

GALPROP WebRun: an internet-based service for calculating galactic cosmic ray propagation and associated photon emissions

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Abstract

GALPROP is a numerical code for calculating the galactic propagation of relativistic charged particles and the diffuse emissions produced during their propagation. The code incorporates as much realistic astrophysical input as possible together with latest theoretical developments and has become a *de facto* standard in astrophysics of cosmic rays. We present GALPROP WebRun, a service to the scientific community enabling easy use of the freely available GALPROP code via web browsers. In addition, we introduce the latest GALPROP version 54, available through this service.

Keywords:

astroparticle physics — diffusion — elementary particles — cosmic rays — ISM: general — dark matter — diffuse radiation — gamma rays: ISM — infrared: ISM — radio continuum: ISM — X-rays: ISM

1. Introduction

A large number of outstanding problems in physics and astrophysics are connected with studies of cosmic rays (CRs) and the associated diffuse emissions (radio, microwave, X-rays, γ -rays) produced during their propagation. Among these problems are indirect searches for dark matter (DM), the origin and propagation of CRs, particle acceleration in putative CR sources – such as supernova remnants – and the interstellar medium (ISM), Cosmic rays in other galaxies and the role they play in galactic evolution, studies of our local Galactic environment, CR propagation in the heliosphere, the origin of the 511 keV line from the Galactic Center, the origin of the extragalactic diffuse emission, as well as many others. New or improved instrumentation to explore these open issues are operating or under development. Low-energy CR detectors on spacecraft and balloons, such as ACE, TIGER, the Voyagers 1 and 2, provide data on isotopic composition, and are complemented by the currently on-orbit PAMELA experiment, which is designed to measure antiprotons as well as light nuclei, electrons, and positrons above 100 GeV. Elemental spectra are provided up to the TeV range by the experiments CREAM, ATIC, and TRACER, while PPB-BETS, CALET, and the *Fermi*-LAT provide measurements of electrons. Instruments such as INTEGRAL, *Fermi*-LAT, HESS, MILAGRO, MAGIC, and VERITAS cover from hard X-rays to γ -rays up to TeV energies. A number of other experiments are in the research phase, under construction, or about to be launched, for example, AMS, OASIS, HAWK, and CREST. For a recent review see [35].

The complex nature of these scientific goals, such as, e.g., the detection of a weak DM signal on top of the intense diffuse γ -ray emission produced by CRs interacting with the ISM, or the study of K-capture isotopes and electrons in CRs, requires *reliable and detailed calculations* using a numerical model. All of the latest developments of astrophysics, and particle and nuclear physics, play a role in addressing these questions: the latest developments in CR acceleration and transport mechanisms, detailed maps of the three-dimensional Galactic gas distribution, detailed studies of the interstellar dust, radiation field, and magnetic field, as well as the Local Bubble, and new particle and nuclear cross section data and codes. Achieving these scientific goals requires a realistic, yet simple to access and use, model with most of the technical details left to experts. Alternatively, sophisticated users must have access to the full source code and documentation to easily allow them to modify the code as suits their purpose.

GALPROP is a numerical code for calculating the propagation of relativistic charged particles and the diffuse emissions produced during their propagation. The GALPROP project has been running since the mid-1990s, and since then it has evolved into a sophisticated, efficient, configurable tool for high energy astrophysics [56]. The code incorporates as much realistic astrophysical input as possible together with latest theoretical developments. GALPROP calculates the propagation of CR nuclei, antiprotons, electrons and positrons, and computes diffuse γ -rays and synchrotron emission in the same framework. Each run of the code is governed by a configuration file allowing the user to specify and control many details of the calculation.

galprop.stanford.edu
studies of cosmic rays and galactic diffuse gamma-ray emission

CODE WEBRUN FORUM RESOURCES PUBLICATIONS CONTACTS BUGS?

Search GALPROP web site Search Logout [avladim]

GALPROP version: 54
click to change

WebRun Help

Configure & Submit

Help: Configure & Submit

First-time User Mode

Advanced User Mode

Batch Runs

Monitor Queue

Download Results

Exchange Runs

Please remember to cite GALPROP

Enter the desired GALPROP v. 54 parameters and click 'Submit' at the bottom of the form ↓

Common Grids Propagation Gas Sources Emission Abundances

Import configuration from: you can use an example or retrieve your old run

Common Parameters

Name	Value	Description
Title	Untitled WebRun c	Descriptive title used to identify the run.
n_spatial_dimensions	2	Specifies whether 2 or 3 spatial dimensions.

Energetic and Spatial Grids

Name	Value	Description
r_min	0.0	Minimum galactocentric radius (R) for 2D case, in kpc. Ignored for 3D.
r_max	25.0	Maximum galactocentric radius (R) for 2D case, in kpc. Ignored for 3D.
dr	1.0	Cell size in galactocentric radius (R) for 2D case, in kpc.
z_min	-04.0	Minimum height for 2D and 3D case, in kpc.
z_max	+04.0	Maximum height for 2D and 3D case, in kpc.
dz	0.2	Cell size in z for 2D and 3D case, in kpc

Figure 1: The GALPROP WebRun service allows users to create a GALPROP model using a web browser, validate the model parameters to reduce the likelihood of misconfigured runs, and execute the GALPROP code on a dedicated computing cluster. The service is accessible via <http://galprop.stanford.edu/webrun/>.

Thus, each run of the code corresponds to a potentially different “model”. The code is written mainly in C++ along with some well-tested routines in Fortran 77.

Formalism and results of the GALPROP code can be found in papers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19], conference proceedings [20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32], and reviews [33, 34, 35].

Until now, the only way to use the GALPROP code has been downloading the source code from the project web site, installing and running it on a user’s machine. Besides occasional problems with the installation process, users often experienced difficulties configuring the GALPROP runs.

2. The GALPROP WebRun service

The GALPROP WebRun service presented here enables any member of the scientific community to use the most recent version of GALPROP via a web browser. Installation of the code locally is not required with the calculations performed on a dedicated computing cluster employing AMD Opteron 6174 CPUs managed by the GALPROP team (cluster specifications are given in Section 4). In addition, using the input web forms of WebRun allows the input parameters to have sanity checks applied via rules written by the GALPROP team, thus minimizing the risk of misconfigured GALPROP runs (see Figure 1 for an example). Each user has a queue that can be used for batch jobs of multiple GALPROP runs, where the user load is dynamically distributed across the available compute nodes. We

also provide the latest stable release of GALPROP along with earlier tagged releases to allow cross-checking of results across different versions.

The results of a GALPROP run (CR distributions and diffuse emission sky maps) are written out in FITS files readable by common astronomical software [36]. Some of this data (e.g., energy spectra of CR isotopes, abundances of CR species, and spectra of diffuse emissions) can be plotted using the WebRun interface. The output of a GALPROP run generally contains much more usable information than given by the built-in plot templates in GALPROP WebRun, so users are encouraged to build their own plotting routines that use the data files produced by GALPROP.

WebRun stores the results of each run along with the GALPROP configuration file on the web server from where the author of the results can download them as a compressed ‘tar’ archive. Sharing the results is also made easy by WebRun: the author of the run can publish the URL of the tar archive, which will make it possible for anyone to download and peruse the results. The URLs of user-generated WebRun archives are encoded with a string of 16 random characters. This string acts as a key to the run known only to the user that generated it, unless he or she decides to share or publish the URL.

The GALPROP WebRun service can be accessed on the World Wide Web [37]. Registration is required to use WebRun, which is done via a form at the WebRun URL.

3. New features in the latest GALPROP version 54

Simultaneously with the release of the WebRun service, we present an improved version the GALPROP code (v54). This version is available to the scientific community only via the GALPROP WebRun site. The new features of the code include:

- Shared-memory parallel support with OpenMP to take advantage of multi-processor machines;
- Memory usage optimization;
- Implementation of the HEALPix output of gamma-ray and synchrotron skymaps. The HEALPix format [38] is a standard for radioastronomy applications, as well as for such instruments as WMAP, Planck etc.;
- Implementation of the MapCube output for compatibility with Fermi-LAT Science Tools software [39];
- Implementation of gamma-ray skymaps output in Galactocentric rings to facilitate spatial analysis of the Galactic diffuse gamma-ray emission;
- More accurate line-of-sight integration for computing diffuse emission skymaps;
- 3D modeling of the Galactic magnetic field, both regular and random components, with a range of models from the literature, extensible to any new model as required;
- Calculations of synchrotron skymaps on a frequency grid, using both regular and random magnetic fields;
- Improved gas maps, which are computed using recent H I and CO (H₂ tracer) surveys [40, 41], with more precise assignment to Galactocentric rings;
- A new calculation of the Galactic interstellar radiation field using the FRaNKIE code (Fast Radiation transport Numerical Kode for Interstellar Emission, as described in [17]) and implementation of the corresponding changes in GALPROP;
- Considerably increased efficiency of anisotropic inverse Compton scattering calculations;
- GALPROP code is compiled to a library for easy linking with other codes (e.g., DarkSUSY [42], SuperBayeS [43]);
- Numerous bug fixes and code-style improvements;
- Improved configuration management via the GNU auto-tools. Multiple *NIX system and compiler targets (gcc, intel, llvm, open64) are supported;
- Bugzilla available at the GALPROP WebRun URL for user-submitted bug tracking.

4. Computing cluster specifications

WebRun runs on a cluster comprised of a head node, which is used as a web and data server, and four compute nodes that are connected with Gb ethernet and Infiniband links. The head node is 2-way machine using 12-core AMD Opteron 6174 processors with 64 GB of physical memory and 16 TB of redundant data storage. Each compute node is a 4-way system using 12-core AMD Opteron 6174 processors with 128 GB of physical memory and a modest amount of local storage via redundant disks (2 × 300 GB mirrored drives) for the operating system and other critical files. Data sets and other common files are shared via NFS from the head node, as is the common storage area that run results from the compute nodes are written to. Since the current GALPROP parallelization scheme uses a shared memory model (via OpenMP), these AMD-based systems have enabled us to consolidate computational and memory resources within a single unit to enable even high-resolution 3D calculations. In addition, these systems allow us to easily extend the parallel calculations to CPUs and add-in GPU cards using, e.g., OpenCL, or even a hybrid MPI/OpenMP/OpenCL scheme (with some rearchitecting) to use more than one compute node in the future. Similar capabilities were not possible with, e.g., a blade-based system given our power and cost-per-unit requirements. At any rate, this relatively modest system is easily extended dependent on demand for the WebRun service.

The GALPROP WebRun cluster uses the CentOS [44] Linux distribution along with the OSCAR [45] software suite that is used to install, configure, and synchronize, the software across the cluster. The run queue and resource allocation for user runs of GALPROP via WebRun are managed using TORQUE [46] in combination with Maui [47]. User registration and authentication in WebRun is linked to a database on the GALPROP forum, which based on the open source bulletin board software phpBB [48]. A Bugzilla [49] is provided for bug tracking and feature requests. The front end of GALPROP WebRun, i.e., the browser-based user interface, as well as the back-end routines interacting with the cluster software, are a PHP-based custom product developed by the GALPROP team.

GALPROP WebRun calculations submitted via the web interface are added to a run queue. If enough cores are available for computation, the calculation in the queue starts immediately. Otherwise, the queue manager schedules runs in such a way that each WebRun user gets a fair share of resources, and available hardware is used at maximum capacity. Currently, all GALPROP v54 runs are assigned 12 cores and up to 16 GB of memory per run, resulting in typical run times for a GALPROP calculation ranging from a few minutes (if only 2D cosmic-ray propagation is involved) to several hours (if high resolution 3D cosmic ray/diffuse emission calculations are performed). The legacy GALPROP (v50) does not support multithreading, and each calculation with this version of GALPROP is given 1 processor core. Our policy for allocation of computing resources may change in the future in order to better serve users interested in computationally intensive or batch runs. Users are encouraged to provide feedback on their experience with GALPROP WebRun to the development team.

5. Using the GALPROP WebRun service

The interface of WebRun consists of a narrow sidebar menu on the left and a wider main panel on the right of the screen (see Figure 1). The links in the sidebar menu open in the main panel the interface sections ‘WebRun Help’, ‘Configure & Submit’, ‘Monitor Queue’, ‘Download Results’ and ‘Exchange Runs’, and the workflow of running and working with a calculation follows the sequence in which these sections are ordered.

When users first log on and visit the WebRun page, they see the ‘Configure & Submit’ section, in which a default GALPROP model is loaded. The default model does not correspond to any published results, but serves as a base with most parameters set to reasonable values. More models reproducing published results are provided as examples accessible via the drop-down menu at the top of the main panel. To assist the user, in the ‘Configure & Submit’ section, GALPROP parameters are arranged into groups (the groups are navigable via scrolling or a shortcut bar at the top of the main panel), and some parameters are hidden to simplify navigation. The sidebar menu features options ‘First-time User Mode’ and ‘Advanced User Mode’, with more parameters visible in the latter. In both modes, some parameters are hidden or shown depending on values of other parameters. For example, when the user changes the GALPROP parameter ‘gamma_rays’ from its default value of ‘0’ to ‘1’, additional parameters in the ‘Gamma-Ray Emission’ group appear, such as ‘skymap_format’, which was irrelevant for ‘gamma_rays’ equal to 0. To see all parameters, the user may choose the ‘Advanced User Mode’ and check the box ‘Show Inactive Parameters’ in the sidebar menu. Some parameters, such as names of gas and dust maps, debugging-related and obsolete parameters, are fixed and cannot be edited in WebRun, but can be perused by checking the box ‘Show fixed parameters’. At the bottom of the main panel, the button ‘Submit’ saves the user-specified model parameters and sends them to a validation routine, which helps prevent misconfigured runs by providing detailed warning messages when parameters are out of range or have conflicting values. Upon a successful validation (or if the user chooses to ignore the warnings), the user will be prompted for a confirmation and given the option to download the formed GALDEF file (i.e., the GALPROP configuration file with specified parameter values). Detailed explanation of the meaning of all parameters is provided in the web form and in the GALPROP Explanatory Supplement [50].

When the user confirms the run, it will be submitted to a run queue on the GALPROP computing cluster, and the user will be taken to the WebRun section ‘Monitor Queue’ (see Figure 2). The main panel in this section contains: a list of queued and running calculations on the left; a configuration viewer panel on the right, which displays the configuration file and control buttons (‘Stop’ and ‘Import’) for the run selected from the list; and a real-time monitor at the bottom, which displays the chosen calculation’s running output or the status of the cluster. Parameter ‘Title’, displayed along with the calculation number in the list, is very helpful in organizing and identifying one’s runs. While the user may close the browser and/or log out from the GALPROP web site, it will not stop queued or running calcu-

lations. The runs will be finished, packaged and moved to the list in the ‘Download Results’ section regardless of the user’s online status.

Completed runs may be viewed in section ‘Download Results’, interface layout of which is similar to that of the ‘Monitor Queue’ section, but there is no monitor panel (see Figure 3). Clicking a run in the list displays its configuration and controls in the viewer panel: ‘Download’, ‘View Log’, ‘Quick Plots’, ‘Import’ and ‘Delete’. The ‘Download’ button displays the link to the archive file with FITS files produced by GALPROP, and this link can be shared with the public, yet it is protected from unauthorized access by a random 16-character suffix. The run-time log produced by the code, included in the archive, can also be viewed online using the ‘View Log’ button. ‘Quick Plots’, a convenient tool illustrated in Figure 4, allows one to take a quick look at the results of the run. The ‘Import’ button is useful for making a number of similar calculations. Clicking the button takes the user to the ‘Configure & Submit’ section, where the values of all parameters are identical to those in the imported run. Deleting the run using the ‘Delete’ button irreversibly removes it from the run list and also erases it from the hard drive on the server, but the record of that run (user id, run id, timing information and exit status) is retained for usage statistics collection.

There are two more functions available in WebRun: batch runs and run exchange. The link to batch runs can be found in the sidebar menu in the ‘Configure & Submit’ submenu. To execute a batch of runs, the user can submit an archive in *ZIP* or *tar* format with GALDEF files using this function. Run exchange is instrumental for collaborations, allowing any registered user to gain access to the log, Quick Plots and Import capability of another user’s run, as long as the link to the archive has been shared. Both of these functions are documented in the help pages and within the interface.

6. Getting help and providing feedback

The GALPROP WebRun service includes help pages and a FAQ that explains the features of the web interface to the GALPROP code. Information about the GALPROP code is available from the GALPROP web site [50]. A forum on the GALPROP web site [51] allows registered GALPROP users to discuss the code, ask the developers additional questions, and provide feedback.

7. How to acknowledge the use of GALPROP and WebRun

If GALPROP is used to obtain results for your publication, please cite all GALPROP papers relevant to your results and the address of the GALPROP web site [52]. In addition, if the WebRun service is used, also cite the present paper, Vladimirov et al., 2010 in *Computer Physics Communication*. These terms may be updated in the future, with up-to-date instructions in the ‘Terms of Use’ section of the GALPROP web site [53].

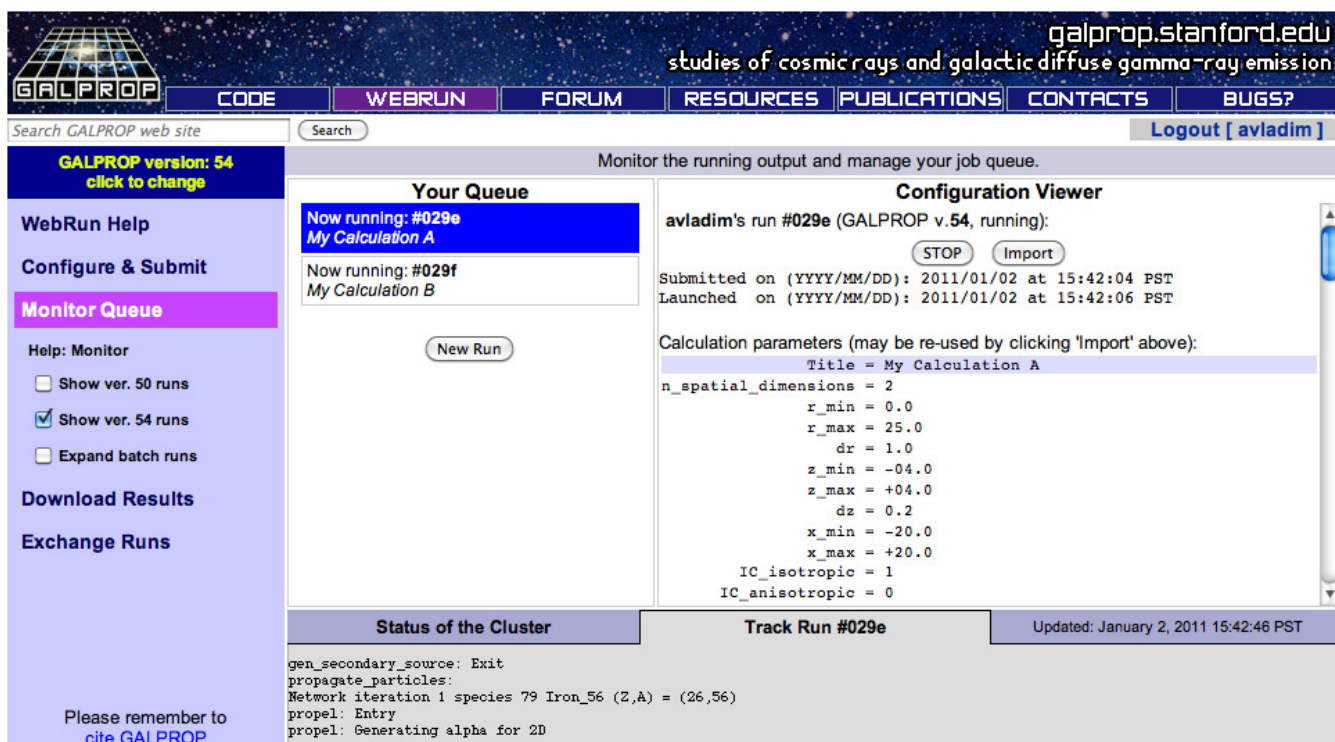


Figure 2: GALPROP calculations in WebRun are executed on a dedicated computing cluster at Stanford University. A job queue with multiple simultaneous runs is supported. Each calculation is parallelized across several processor cores, and real time running output can be viewed via the WebRun page.

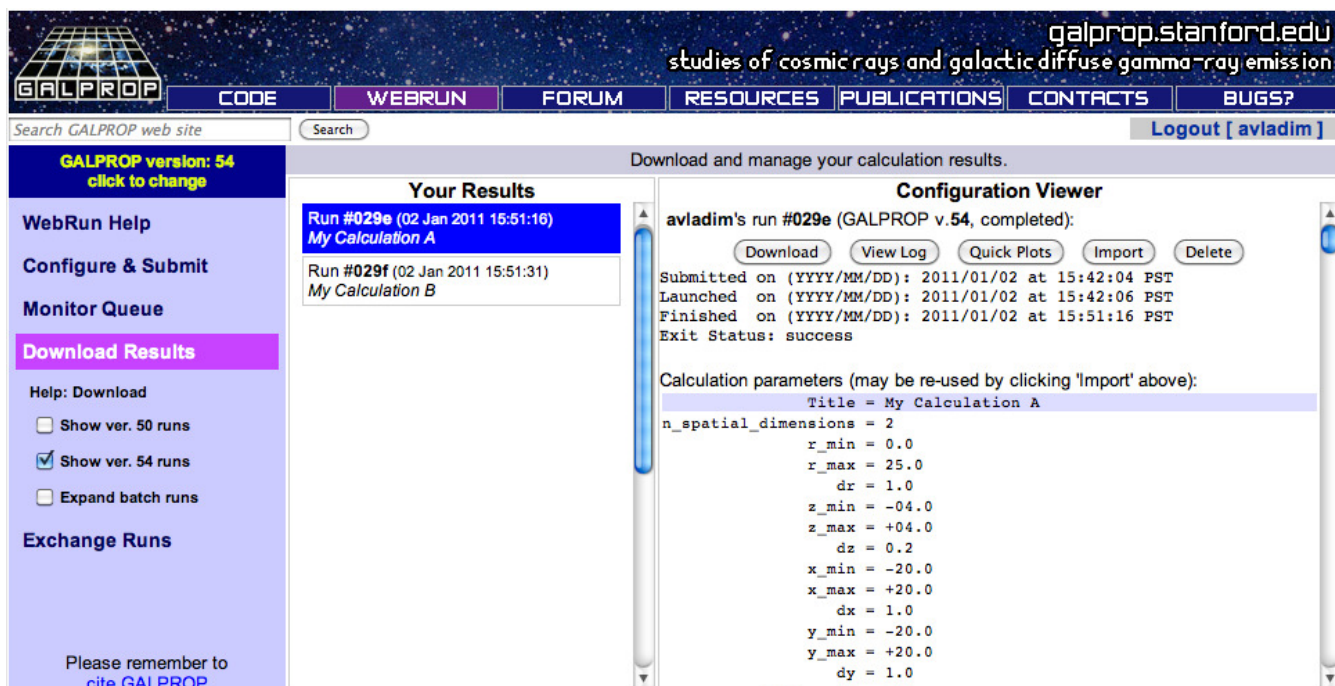


Figure 3: GALPROP WebRun users have access to and control over archives with results of all calculations they have performed. Each archive can be shared by publishing its URL. Visualization of results is possible within the WebRun window via the 'Quick Plots' function.

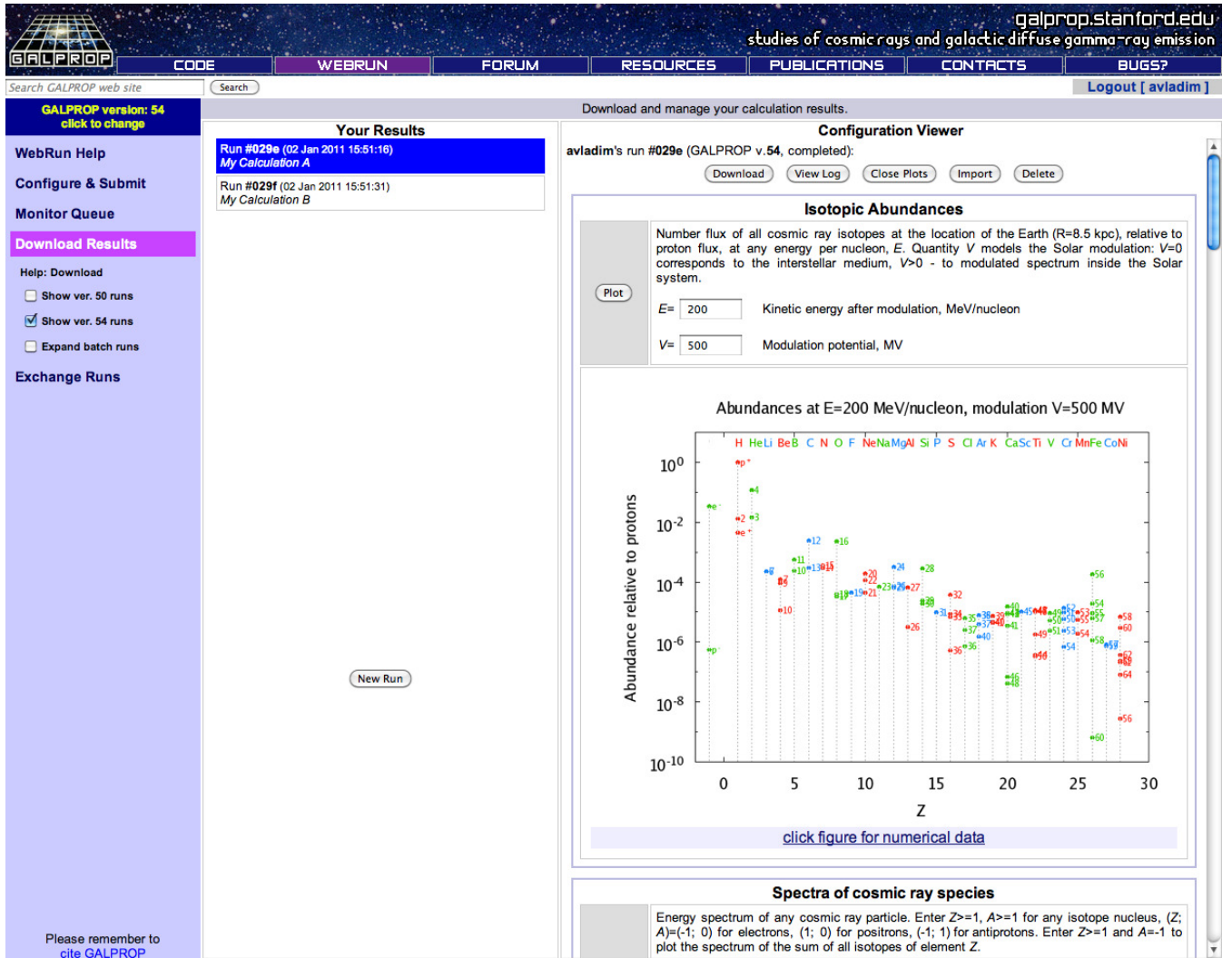


Figure 4: Quick Plots is an online plotting tool in GALPROP WebRun, capable of parsing the FITS files produced by GALPROP and creating raw text data tables and plots using built-in templates. Users are encouraged to develop their own plotting routines for publication purposes using the data produced by Quick Plots as a reference.

8. Acknowledgements

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